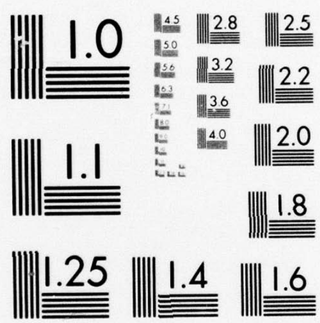
AD-A040 308 TEXAS A AND M UNIV COLLEGE STATION DEPT OF ELECTRICA--ETC F/G 17/7
A LOW COST NAVIGATION MICROPROCESSOR SYSTEM.(U)
MAR 77 S SURARATRUNGSI, P S NOE AF-AFOSR-2965-76
UNCLASSIFIED AFOSR-TR-77-0633 NL

| OF |
AD A040308

END
DATE FILMED
7-77


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ADA040308

18 19 **REPORT DOCUMENTATION PAGE** — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFOSR - TR - 77 - 0633
2. GOVT ACCESSION NO.: 2
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): 6 A LOW COST NAVIGATION MICROPROCESSOR SYSTEM.
5. TYPE OF REPORT & PERIOD COVERED: 9 Interim rept.,
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): 10 Songsuk/Suraratrungsi, Philip S./Noe
8. CONTRACT OR GRANT NUMBER(s): 15 AF-AFOSR-2965-76 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Texas A&M University, Department of Electrical Engineering, College Station, Texas 77843
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F, 16 2304/A1, 17 A1
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Office of Scientific Research/NM, Bolling AFB DC 20332
12. REPORT DATE: 11 March 1977
13. NUMBER OF PAGES: 3
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 4p.
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DDC RECEIVED JUN 8 1977 C

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

IECI '77 Proceedings, Industrial Electronics and Control Instrumentation, March 21-23, 1977, pp 36-38.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Global Positioning System (GPS) is a satellite-based radio navigation system currently under development by the Department of Defense. This paper describes the feasibility of a microprocessor implementation as part of a low-cost GPS receiver. A noisy model is considered in the dynamic system simulation. A total of 726 fixes are taken during a six-hour flight with an RMS error of 31.59 ft. Results are compared with a similar run on an Amdahl 470V/6.

New 410214

AD No.
DDC FILE COPY

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

LB

AFOSR - TR - 77 - 0633
IECI '77 PROCEEDINGS - INDUSTRIAL ELECTRONICS AND CONTROL INSTRUMENTATION, MARCH 21-23, 1977

A LOW COST NAVIGATION MICROPROCESSOR SYSTEM

S. Suraratrungsi and P. S. Noe

ABSTRACT

The Global Positioning System (GPS) is a satellite-based radio navigation system currently under development by the Department of Defense. This paper describes the feasibility of a microprocessor implementation as part of a low-cost GPS receiver. A noisy model is considered in the dynamic system simulation. A total of 726 fixes are taken during a 6-hour flight with an RMS error of 31.59 ft. Results are compared with a similar run on an Amdahl 470V/6.

INTRODUCTION

The NAVSTAR/Global Positioning System (GPS) is a satellite-based radio navigation system authorized for development by the Department of Defense in December 1973. Early in the 1980s a complete system consisting of 24 satellites will orbit the earth in circular 12-hour orbits at an altitude of 11,000 nautical-miles and inclined at 63° to the equator. The satellites will transmit pseudo-random noise codes and ephemerides to the users worldwide. The user, equipped with a small receiver, receives and processes the navigation signals from which he will be able to determine his location, velocity, and system time.

Hard-wired processors and minicomputers have been used effectively as the major processing tool for satellite navigation in the past, but high cost and weight impose a practical limitation for these systems to certain classes of users. Recently the advent of low-cost, high-performance large-scale integrated microprocessors have eliminated this limitation. Microprocessors have several advantages over hard-wired processors such as: low cost, light weight, less power consumption, reliability, and flexibility. These advantages make it feasible to develop a microprocessor-based design for a low-cost GPS receiver. It is the objective of this paper to show the feasibility of such a GPS receiver.

THE ALGORITHM

The fundamental problem in the implementation of a GPS low-cost receiver is described in [2]. This problem involves the computation of user position components u_1, u_2, u_3, and clock bias b which can be obtained from the spherical navigation equations

$$\sum_{j=1}^{3} (x_{ij}-u_j)^2 = (r_i-b)^2, \quad i=1,\dots,4 \tag{1}$$

where x_{ij}, $j=1, 2, 3$ = three known position components of i^{th} satellite (as adetermined from the ephemeris data)

u_j = three receiver coordinates (as determined from the estimated latitude, longitude, and altitude of the receiver)

r_i = range from the i^{th} satellite to the user

b = clock bias

Rearranging (1) and solving for r_i gives

$$r_i = \left[(x_{i1}-u_1)^2 + (x_{i2}-u_2)^2 + (x_{i3}-u_3)^2\right]^{1/2} + b \tag{2}$$

Obtaining a Taylor series expansion gives

$$r_i = \bar{r}_i + (\partial r_i/\partial U)\Big|_{\bar{U}}\delta U + (\partial^2 r_i/\partial U^2)\Big|_{\bar{U}}\delta^2 U + \dots, \tag{3}$$

where $\bar{U}$ is the user's estimate of U and $\bar{r}_i$ is computed by substituting $\bar{U}$ into (2).

Linearizing (3) by retaining only the linear terms gives

$$\delta r_i = \left[\partial r_i/\partial u_1 \quad \partial r_i/\partial u_2 \quad \partial r_i/\partial u_3 \quad \partial r_i/\partial b\right]\Big|_{\bar{U}}\delta U \tag{4}$$

where $\delta r_i = r_i - \bar{r}$ and $\delta U = U - \bar{U}$

Now define $r_i = h_i \delta U$ (5)

where h_i is the row vector in (4) given by

$$h_i = \left[(u_1-x_{i1})/(r_i-b)\,(u_2-x_{i2})/(r_i-b)/(u_3-x_{i3})/(r_i-b)\ 1\right]\Big|_{\bar{U}} \tag{6}$$

Thus

$$\delta R = \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \end{bmatrix} \delta U = H\delta U \tag{7}$$

where H is the 4x4 matrix of partials of R with respect to U, evaluated on $\bar{U}$, and $R = \left[r_1 \quad r_2 \quad r_3 \quad r_4\right]^T$.

The desired position correction are

$$\delta U = H^{-1}\delta R \tag{8}$$

The update-estimated position is

$$\bar{U}_k = \bar{U}_{k-1} + \delta U_k \tag{9}$$

Convergence is controlled and determined by comparing δU with an arbitrary minimum value, ε.

The Hotelling algorithm [3] was proposed in [2] to be used to iteratively update H^{-1} in (8) as the major t

Manuscript received This work was supported by the U.S. Air Force Office of Scientific Research, under Grant AFOSR-762965.

The authors are with the Department of Electrical Engineering, Texas A&M University, College Station, Texas, 77843.

in solving for successive GPS position fixes [2]. This feature is implemented as step (6) below.
In summary, the algorithm suggested in [2] proceeds as follows:

1) Guess initial $\overline{U}$; select 4 satellites; compute $G=H^{-1}$.
2) Obtain r_i and x_{ij} from receiver data for $i=1\to4$.
3) Calculate $\overline{r}_i$ for all i.
4) Obtain $\delta R = R-\overline{R}$.
5) Obtain H matrix from (6).
6) Obtain $G_m=G_{m-1}\left[2I-HG_{m-1}\right]$. If $\left|G_m-G_{m-1}\right| > \varepsilon_1$ repeat step 6); otherwise, go to 7). Here G_{m-1} is the last estimate of the inverse of H and I is the identity matrix.
7) Obtain $\delta U=G_m\delta R$.
8) Update position estimate $\overline{U}_k=\overline{U}_{k-1}+\delta U_k$. Repeat step 3) through 8) if $\delta U>\varepsilon_2$, a specified tolerance; otherwise return to step 2).

SIMULATION MODEL

Satellite position and mission profile data for a USAF C5A aircraft are generated in realistic computer simulation programs, SATGEN and PROFGEN, respectively. The programs were developed at the Air Force Avionics Laboratory, WPAFB, Ohio.

Satellite Position Generator (SATGEN)

The Satellite Position Generator (SATGEN) simulates the propagation of 24 GPS satellites in 3 equally spaced orbit planes at 63° inclination. Each orbit plane contains a ring of 8 satellites which are equally spaced 45° apart. The satellites in each of 3 orbit planes are also positioned so that the satellites crossing the equatorial plane (ascending nodal crossing) are 15° apart.

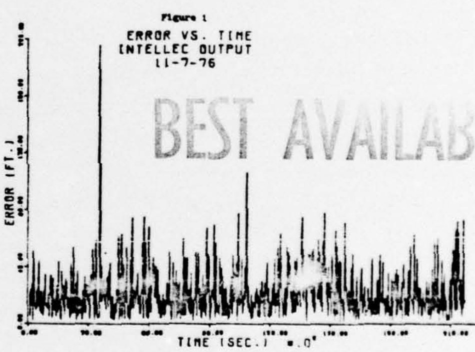
The SATGEN program contains an algorithm that tests which satellites are in view with respect to the user's estimated position, and subsequently four satellites are selected for navigation based on the established criterion, minimum Geometric Dilution of Precision (GDOP) [4]. Currently two satellite selection routines used in [2] were considered-OPTSEL and SATSEL. The OPTSEL routine computes the GDOP for all possible combinations of satellites that are in view and selects 4 satellites with minimum GDOP. The SATSEL, on the other hand, selects three satellites among those satellites in view. The satellites selected are those each of which has a largest component along x, y, and z coordinates respectively (earth centered, earth fixed coordinate system). The fourth satellite is chosen such that the combination with previously chosen three satellites will result in minimum GDOP. Although the SATSEL routine is a suboptimal procedure, it provides computational advantages over the optimal GDOP routine, OPTSEL. For example, if n satellites are in view, $\binom{n}{4}$ GDOP computations are required to determine the optimal set of satellites. On the other hand the suboptimal method requires only n-3 GDOP computations. The SATSEL routine was used in the simulation.

Mission Profile Generator (PROFGEN)

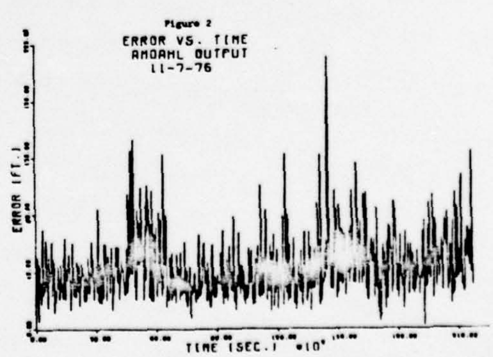
The C5A mission profile data representing a simulated 6-hour flight from Travis AFB, California, to Hickman Field, Hawaii, were generated by the USAF Avionics Laboratory, WPAFB, Ohio. These data are referenced by two angular coordinates (latitude-longitude) and the altitude above the reference ellipsoid (latitude-longitude-altitude coordinate system). Since calculations in space are best carried out in earth centered, earth fixed (ECEF) coordinate system, the USAF C5A mission profile data were transformed to ECEF coordinate system by the PROFGEN routine.

SIMULATION RESULTS

The position fixing algorithm [2] is implemented on the Intellec 8/MOD 80 microcomputer development system which utilizes an Intel 8080 microprocessor with an instruction cycle time of 2 μsec. The algorithm requires 7k bytes of read-only memory (ROM) for program storage and 4k bytes of random access memory (RAM) for data storage. A USAF C5A flight is simulated with noise in the data generated by the satellite and mission profile routines. Position fixes are obtained every 30 seconds and the satellites are selected every 15 minutes. A total of 726 fixes are taken during a 6-hour flight with $\varepsilon_2=10^5$ ft. in step 8) of the algorithm as the convergence criterion. With this value of ε_2 only one iteration is required for each fix, and the errors are 220 ft. or less as shown in Figure 1.



A similar run on the Amdahl 470V/6 computer produces comparable results as shown in Figure 2. Duplicate results are not achieved due to different pseudo-random number generator routines used in the noise model for the two machines.



It should be pointed out that the Amdahl 470V/6 computer, used in the simulation along with the Intellec 8, is for comparison purposes only.

Computation time on the Intellec is 10 s/fix. As far as the speed is concerned, fixing time on the Intellec is quite slow but perhaps suitable for low-cost GPS applications. The 8-bit microprocessor is a handicap for this system if the 10 s/fix rate is considered to be too slow.

CONCLUSION

It has been shown that the simulation results from the microprocessor system are comparable with those from a general purpose computer as far as the accuracy is concerned. Processing speed, on the other hand, is quite slow on the 8-bit machine but can be improved. The following are some techniques which are recommended for improving the processing power of the system:

1. A 16-bit microprocessor can be used instead of an 8-bit machine for this system. Because its 16-bit capability can process 16 bits at a time, it can provide greater speed than the system built with an 8-bit microprocessor. Moreover, a 16-bit system can work with shorter programs using less memory.
2. Since most microprocessor speed is usually faster than memory access time, the processing speed is mostly limited by the speed of the memory. To compensate for this mismatch a high-speed memory can be considered.
3. Use the hardware multiply/divide unit to process the data instead of using the shift and add algorithm from the software. This saves programming steps and hence increases processing speed.
4. Utilize multiprocessor structure in the system where each independent task is handled by a dedicated microprocessor or set of microprocessors.
5. Alternatively, the bipolar bit-slice microprocessor can offer processing power which is far greater than that presently available from MOS microprocessors. By packing their processing power on several matched LSI chips, they are easily expandable to 16-bit or even 32-bit word lengths, and they can be microprogrammed to handle the most powerful high-level instruction set available. However, a bit-slice microprocessor is considered more expensive than those of MOS microprocessors. A trade-off between speed and cost should be carefully considered in the design.

The discussion and recommendations outlined above leads to the conclusion that a microprocessor or a set of microprocessors is a feasible way to implement the processing part of a low-cost GPS receiver.

REFERENCES

[1] H. Shoemaker, "The NAVSTAR/Global Positioning System," Proc. NAECON '75 Conf., Dayton, Ohio, June 10-12, 1975.

[2] P. S. Noe and K. A. Myers, "A Position Fixing Algorithm for the Low-Cost GPS Receiver," IEEE Trans. Aerosp. Electron. System., vol. AES-12, pp. 295-297, March 1976.

[3] V. N. Fadeeva, Computational Methods of Linear Algebra., New York: Dover, 1959 (Transl.: C. D. Benster).

[4] H. B. Lee, A Novel Procedure for Assessing the Accuracy of Hyperbolic Multilateration Systems, IEEE Trans. Aerosp. Electron. System., vol. AES-11, pp. 2-15, Jan. 1975.

Philip S. Noe received his BSEE in 1962 from the Air Force Institute of Technology, WPAFB, Ohio. He received his MSEE and Ph.D. in electrical engineering from the University of Texas at Austin in 1965 and 1970 respectively.

He is currently an Assistant Professor in the Electrical Engineering Department at Texas A&M University, College Station, Texas. His primary area of interest is in digital systems design, where he has published several papers on the state assignment problem, a fast new Boolean function minimization algorithm, and the GPS satellite navigation system. He was a summer faculty fellow in the 1975 ASEE/USAF program where the above article was originally formulated. Microprocessor systems and applications are also one of his major areas of interest.

Songsuk Suraratrungsi was born in Bangkok, Thailand. He received the B.S.E.E. degree from University of Texas at Arlington in 1972 and the M.E.E. from Texas A&M University, College Station, Texas, in 1973. He is presently a doctoral candidate in Electrical Engineering at Texas A&M University.

He has been a Teaching and Research Assistant in the Department of Electrical Engineering at Texas A&M University since 1972.